High Frequency Propagation Studies in the Coastal Environment

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LONG-TERM GOAL

To learn how small scale physical and biological processes contribute to the scattering of high frequency acoustic signals. To understand the relationship between bubble distributions, turbulent flows and related phenomena and the scattered acoustic signal. To develop models of these processes.

OBJECTIVES

To develop improved measurement approaches, carry out high frequency propagation experiments in shallow water environments and interpret the results in terms of contributions due to bubbles, waves, turbulent velocity and sound speed fluctuations.

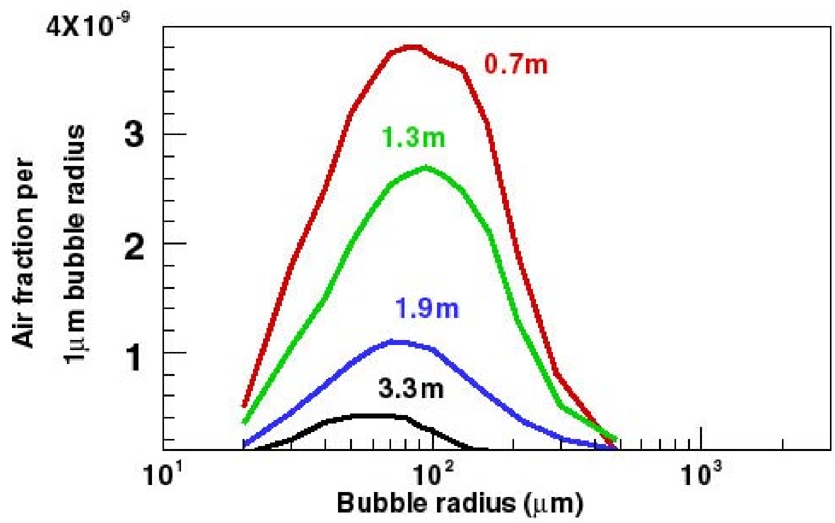

Figure 1: Measured average bubble size distribution in the open ocean, shown in volume scaling to illustrate the dominant peak at a radius slightly below 100μm.

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APPROACH

Our approach has been to develop specialized acoustical instrumentation with which to conduct high frequency (50kHz-300kHz) propagation experiments over modest ranges (100m-2km) using multiple sources and receivers rigidly fixed to the sea floor together with measurements of the relevant physical and biological phenomena and to interpret the results with appropriate models. The instrumentation includes acoustical bubble sensors, high frequency propagation systems, imaging and Doppler sonars. Experiments are carried out in channels and in the surf zone using a variety of transducer configurations (horizontal and 2-d arrays and a combination of back and forward scatter). Independent measurements of the relevant scattering and refractive variability are acquired, including turbulent dissipation and bubble suspensions. Scattering and propagation models are developed as required for both the specialized instrumentation and the propagation studies. Emphasis has been placed on the development of coupled models which include both the oceanographic process, such as bubble injection, dissolution and buoyancy effects, with the resulting acoustic propagation effect. The work described here has been carried out with S Vagle (IOS) and through collaborations with several groups including G Deane (SIO), D DiIorio (SACLANT), Z Ye (NCU Taiwan), C Garrett & R Lueck (U Victoria).

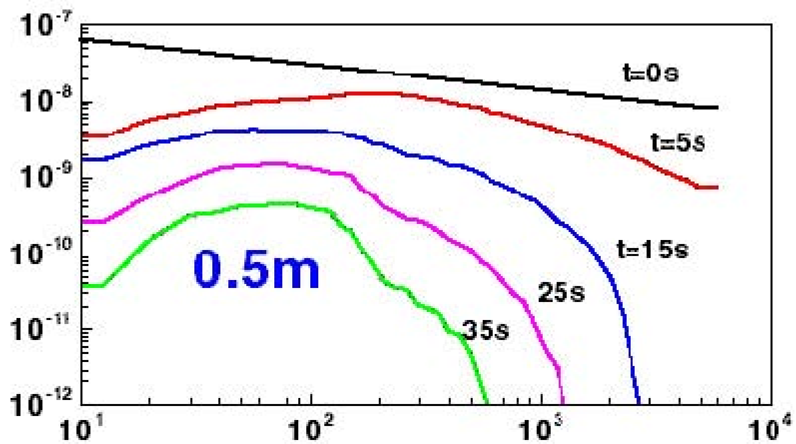

Figure 2: Model calculation of bubble size distribution in volume scaling following injection taking account of buoyancy and dissolution. Note that the high frequency propagation effects depend on the size distribution. Dissolution of small bubbles and buoyancy loss of large bubbles occurs within seconds of the injection, leaving a dominant acoustic target/attenuation frequency of ~30kHz.

WORK COMPLETED

(i) A comprehensive analysis of the performance of an acoustical resonator was completed (Farmer, Vagle & Booth, 1998), together with a comparison between different bubble measurement techniques (Vagle & Farmer, 1998).
(ii) A theoretical basis for combining relevant physical mechanisms affecting bubble distributions, including turbulence, dissolution and buoyancy, has been used to develop a suitable model for the

propagation of high frequency sound through a channel subject to bubble injections by breaking waves or surf.

(iii) Propagation data in the surf zone at Scripps subject to wave and bubble effects has been analysed.

(iv) Forward scatter measurements have been acquired in the outflow of the Bosphorus, together with supporting data describing the stratification and shear.

(v) Measurements of the relative contribution of specular scatter from the ocean surface at different sea states, with and without bubble layers, have been analysed.

(vi) The role of small scale velocity fluctuations on acoustic backscatter beneath breaking waves has been measured with a coherent Doppler sonar.

(vii) A model of scattering from slender bodies, appropriate for analysis of biological scattering in forward scatter experiments, has been completed (Ye et al., 1998).

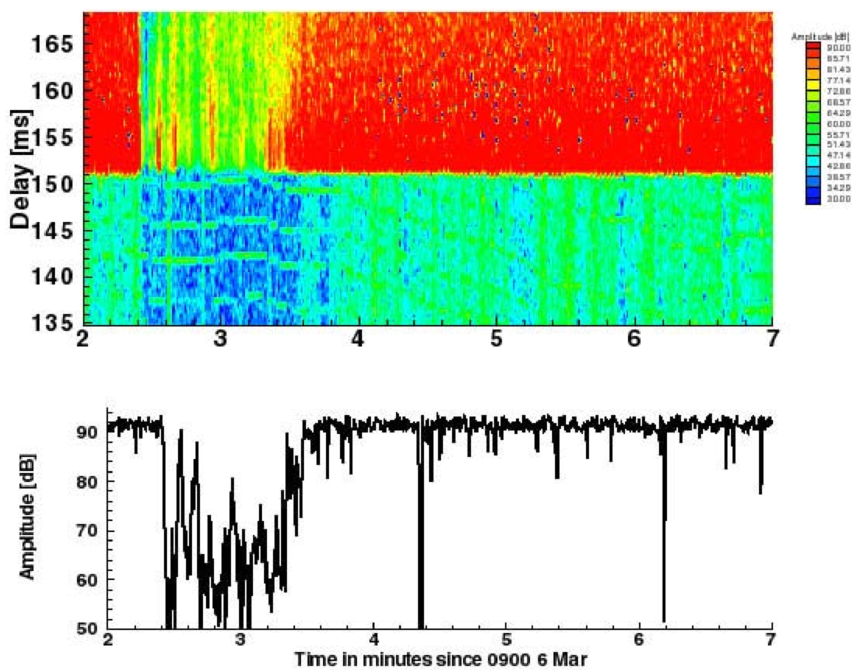

Figure 3: Above: Signal intensity detected along a 200m shallow water path beneath breaking waves, showing almost total masking following bubble injection. Below: magnitude of attenuation corresponding to figure above. Masking lasts for about 1minute.

RESULTS

This year we focused primarily on the role of bubbles on high frequency propagation (Farmer 1998), while continuing our ongoing measurement and analysis program. A theoretical analysis of the acoustical behavior of bubble injections requires inclusion of essential physical phenomena such as dissolution, turbulence and buoyancy effects, since these determine the resulting size distribution and hence the acoustic properties of bubble clouds. Our observations show that in the several different

ocean environments we have studied, the average bubble size distribution in a volume scaling has a peak in the neighborhood of 100μm corresponding to a dominant high frequency attenuation and

scatter at ~30kHz (Fig. 1). However there are subtle but important effects on bubble size distribution dependent on depth and the time after injection. Although turbulence, advection and other factors must also play a role, a theoretical model assuming a power law initial size distribution at injection and incorporating only buoyancy and dissolution appears able to explain this result, thus providing a starting point for acoustical scattering and propagation models of environments where breaking waves occur (Fig. 2).

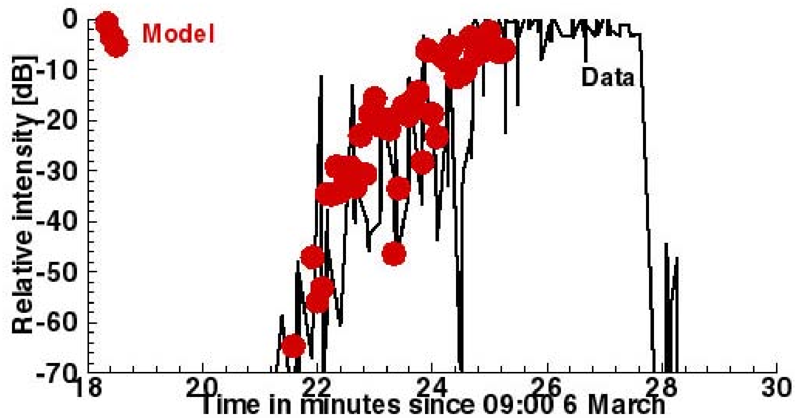

Figure 4:   Comparison of model calculations of the recovery of the sound channel (Fig 3) due to buoyancy and dissolution effects, compared with observations.

Building on our recent studies of high frequency propagation through turbulent flows (DiIorio & Farmer, 1998), we acquired data in a collaborative experiment with SACLANT using a 50kHz system in the Bosphorus. Bottom generated turbulence and mixing, together with ship wake effects, are thought to account for the large fluctuations observed in both amplitude and phase. Bubbles and surface waves have a dominant effect on propagation in shallow or near surface channels. We have investigated these effects in two ways. From measurements in a surf zone at Scripps (Farmer et al. 1997) we find that subsurface bubble clouds can completely block 100kHz propagation (Fig. 3). Acoustic propagation calculations incorporating the buoyancy/dissolution model mentioned above, appear to explain the duration of the blocking and subsequent recovery of the transmission channel (Fig. 4). Further calculations that include the amplification of surface waves propagating into a beach, show their predicted influence on acoustic intensity increases shoreward, due both to the decreasing depth of the propagation channel and amplification of the shoaling waves (Fig. 5).

The role of turbulence on high frequency propagation has been demonstrated by comparisons with independent measurements using moored instrumentation (Fig. 6), showing that path averaged reciprocal transmission measurements of travel time difference are fully consistent with directly measured velocity shear. As part of our longer range goal of determining the combined influence of both turbulence and bubbles on high frequency propagation, we have implemented and tested a high frequency coherent Doppler sonar for resolving turbulence velocity fluctuations at centimeter scales (He, 1997) and deployed this in both the surf zone and open ocean experiments. Finally, as part of our continuing examination of the role of biological targets on high frequency propagation, a model for scattering from slender bodies has been developed in collaboration with Z Ye (Ye et al, 1998).

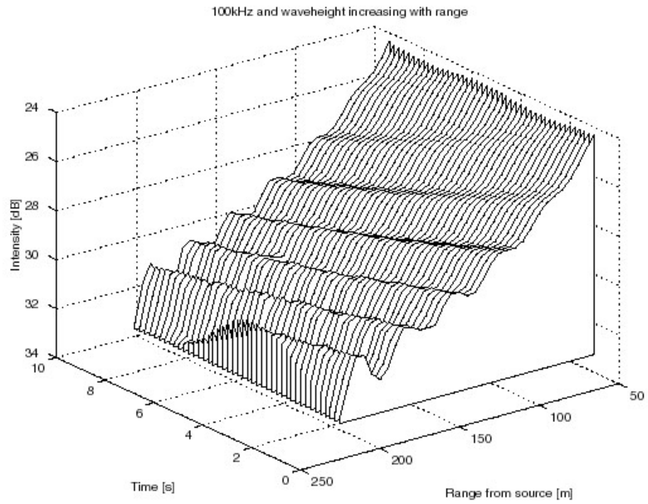

Figure 5: Modeled intensity of 100kHz signal transmitted beneath shoaling waves towards a beach. The predicted influence of the waves increases towards the beach both because of increasing wave height and shallower water.

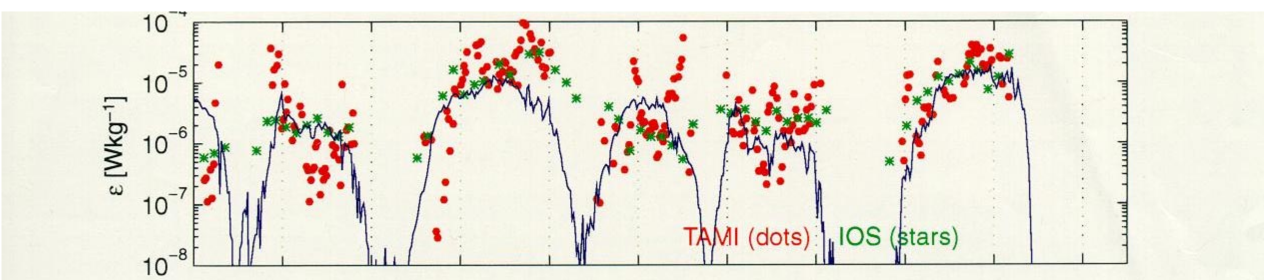

Figure 6: Comparison of path integrated measurements at 67 kHz over a 700m path of turbulent dissipation (green stars) with independent shear probe measurements red dots, (courtesy R Lueck) and a model calculation of expected bottom boundary layer turbulence (blue line).

IMPACT/APPLICATION

High frequency propagation in coastal and near surface waters is sensitive to refractive variability and scattering effects. Such effects can adversely influence performance of synthetic aperture sonars, acoustic telemetry links and other systems that depend on the properties of the propagation channel. Conversely, variability in measured signals can be inverted so as to learn more about the processes such as turbulence and bubble distributions, that account for this variance. As we gain a better understanding of the mechanisms responsible for these propagation effects we can develop improved propagation models. The observations acquired here directly relate to the practical application of high frequency acoustical propagation in coastal and upper ocean waters and are expected to lead to insights on factors affecting performance of imaging, communication and related systems.

RELATED PROJECTS

This work has been carried out in collaboration with SACLANT Centre's study of the Bosphorus, the Scripps Bubble experiment, and the small scale oceanography program on bubbles in the upper ocean boundary layer.

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